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16-QAM Field-Quadrature Decomposition using Polarization-Assisted Phase Sensitive Amplification

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Abstract—Simultaneous I and Q extraction for 16-QAM is experimentally demonstrated through field-quadrature decomposition using a polarization-assisted phase sensitive amplifier. The quadrature components are successfully received and performance is evaluated through bit-error-ratio testing.

Keywords—optical signal processing; phase sensitive amplification; polarization-assisted phase sensitive amplification

I. INTRODUCTION

The use of spectrally efficient multilevel modulation formats such as m-level phase-shift keying (PSK) or quadrature amplitude modulation (QAM) has increased steadily in recent years. Nonlinear all-optical signal processing of such advanced modulation formats has attracted much attention, with the potential of energy and cost reductions over electronic processing [1]. Advantages include broad optical bandwidths and femtosecond response times, enabling ultrafast processing operations such as signal regeneration, wavelength conversion, and format conversion [2]. Electric field quadrature decomposition, extracting the in-phase (I) and quadrature (Q) components of an optical signal, is a useful operation for QAM modulated signals with possible applications in modulation format conversion. For 16-QAM it constitutes a building block towards conversion to four binary signals which would allow real-time direct-detection, or possibly all-optical regeneration through amplitude regeneration and coherent addition of the decomposed parts. Polarization-assisted phase sensitive amplification (PA-PSA) has been established as an effective technique for field quadrature decomposition, with demonstrated applications in regeneration of BPSK and QPSK signals and quadrature decomposition of QPSK signals [3–5].

In this paper we expand the application of PA-PSA and demonstrate experimentally the decomposition of a 16-

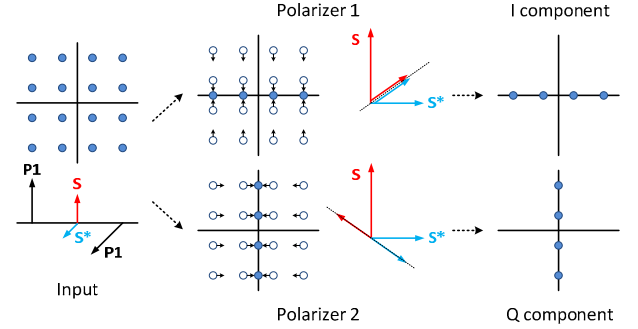


Fig. 1. Field-quadrature decomposition of a 16-QAM signal.

QAM signal, separating its I and Q components. Simultaneous extraction of the I and Q components is verified and bit-error-rate (BER) performance is evaluated for the decomposed signals.

II. PRINCIPLE

As demonstrated in [3–5], PA-PSA involves coherently mixing the signal and idler of a dual pump degenerate vector PSA in a polarizer, as shown in Fig. 1. By adjusting the transmission axis of the polarizer, the signal (S) and its phase conjugated idler (S^*) are added or subtracted with equal amplitude in order to yield the I or Q component of the signal. For 16-QAM the resulting outputs are modulated in a format having two amplitude levels ($\frac{1}{2}$ and $\frac{3}{2}$ of the average output amplitude) and two phase levels (0 and π). This format will be referred to as 4 amplitude-phase-shift keying (4-APSK).

III. EXPERIMENTAL DEMONSTRATION AND RESULTS

In order to investigate the performance experimentally, the setup in Fig. 2 was constructed. Three phase-locked carriers P1 (1538 nm), S (1544 nm), and P2 (1550 nm) to be used

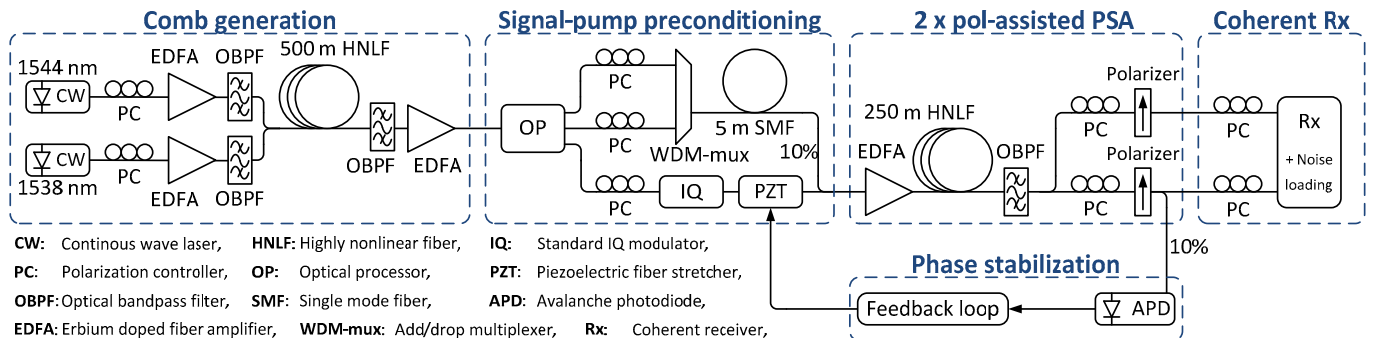


Fig. 2. Experimental setup for 16-QAM field-quadrature decomposition using polarization-assisted phase sensitive amplification.

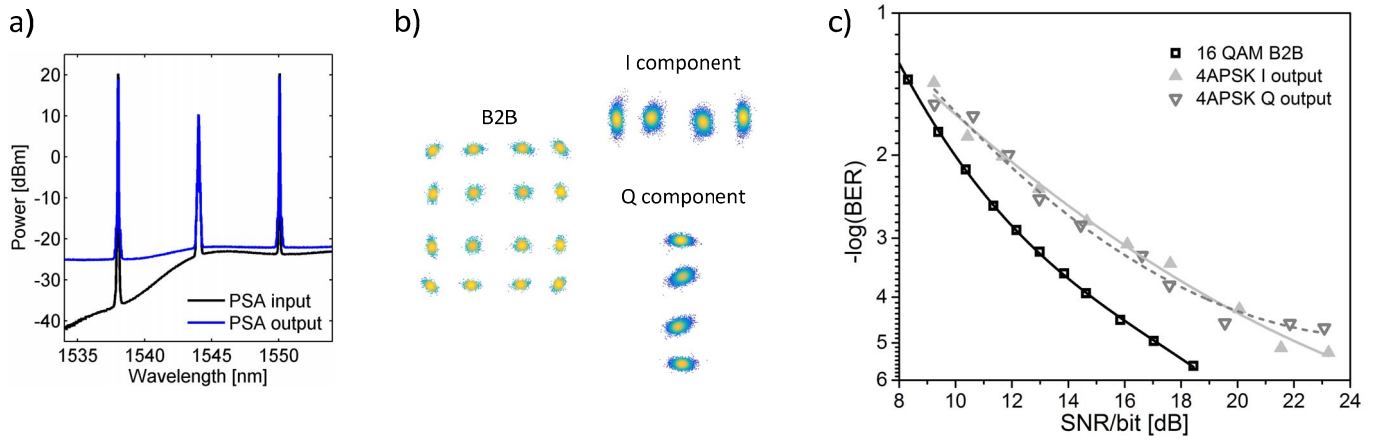


Fig. 3. Experimental results. (a) Input/output spectra of the PSA. (b) System input/output constellation diagrams. (c) BER curves for the back-to-back (B2B) signal and for the decomposed I and Q outputs.

for the PSA stage are generated using four wave mixing in a 500 m highly nonlinear fiber with stable phase-matching for improved non-linear efficiency (HNLF-SPINE). The signal carrier S and the pumps $P1$, $P2$ are separated using an optical processor. S is modulated at 10 GBd with a 16-QAM signal consisting of pseudo-random bit sequences (PRBSs) of lengths $2^{11} - 1$ and $2^{15} - 1$ in the I and Q components, using a standard IQ modulator. The signal and pumps are recombined and their polarizations are adjusted so that $P1$ and S are parallel and orthogonal to $P2$. The separate path lengths are equalized by inserting ~ 5 m of standard single mode fiber. Slow thermal drifts of the relative phases are compensated by an active feed-back phase-control loop based on a low speed avalanche photodiode and a piezo-electric actuator. PSA takes place in a strained 250 m HNLF-SPINE, with the input and output spectra shown in Fig. 3(a). A total input power of 24 dBm and a pump to signal power ratio of 10 dB results in the creation of a phase conjugated idler with a conversion efficiency of -5.1 dB. The pumps are removed using an optical bandpass filter and the orthogonal signal-idler pair is mixed simultaneously in two polarizers aligned to yield the I and Q components. A static phase sensitive extinction ratio of 22.8 dB is observed. The two outputs are passed through a noise loading stage to a coherent receiver and digital storage oscilloscope for offline signal processing. This consisted of clock recovery, radius-directed adaptive equalization using the cost function modification suggested in [7], and carrier recovery using a decision-directed phase-locked loop.

In Fig. 3(b) the measured constellation diagrams are shown for the 16-QAM input and the decomposed I and Q outputs. After quadrature decomposition the $2^{11} - 1$ and $2^{15} - 1$ PRBSs are recovered on the I and Q components respectively, verifying simultaneous extraction of both I and Q. BER is measured for the 16-QAM input B2B (black) and for the 4-APSK modulated I and Q outputs (grey), as seen in Fig. 3(c). For each point a total of 2.4×10^6 symbols are counted, allowing estimation of BERs down to 10^{-5} with at least 100 counted errors. Points have been included below $\text{BER} = 10^{-5}$ with error counts down to 13, corresponding to 99% probability for the actual BER being within a factor of two [8]. We observe that the field-quadrature decomposition

results in a penalty of the SNR required for $\text{BER} = 10^{-2}$ of around 1.5 dB, increasing to around 5 dB for the I and 6 dB for the Q components for $\text{BER} = 10^{-5}$.

IV. CONCLUSION

We have expanded the application of polarization-assisted phase sensitive amplification, and demonstrated electric field-quadrature decomposition of a 16-QAM signal at 10 GBd. We successfully extract the two quadrature components (I and Q) simultaneously. The BER performance have been evaluated and we report SNR penalties of 1.5 dB at $\text{BER} = 10^{-2}$, increasing to 5 dB for the I and 6 dB for the Q components at $\text{BER} = 10^{-5}$.

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REFERENCES

- [1] S. Namiki et al., "Ultrahigh-definition video transmission and extremely green optical networks for future," *IEEE J. Sel. Top. Quantum Electron.*, vol. 17, no. 2, pp. 446-457, March/April 2011.
- [2] S. Wabnitz and B. J. Eggleton, *All-Optical Signal Processing – Data Communication and Storage Applications*, Springer Series in Optical Sciences vol. 194. Springer: Cham, Switzerland, 2015.
- [3] F. Parmigiani et al., "Polarization-Assisted Phase-Sensitive Processor," *J. Lightwave Technol.*, vol. 33, no. 6, pp. 1166-1174, March 2015.
- [4] A. Lorences-Riesgo et al., "Quadrature demultiplexing using a degenerate vector parametric amplifier," *Opt. Exp.*, vol. 22, no. 24, pp. 29424-29434, December 2014.
- [5] N. K. Kjølner et al., "Quadrature Decomposition by Phase Conjugation and Projection in a Polarizing Beam Splitter," in *Proc. Eur. Conf. Opt. Commun. (ECOC)*, paper P.3.8, September 2014.
- [6] J. G. Proakis, *Communication Systems Engineering*, 2nd ed. Prentice Hall: Upper Saddle River, New Jersey, 2002, pp. 405-436.
- [7] E. Pincemin et al., "Novel blind equalizer for coherent DP-BPSK transmission systems: Theory and experiment," *IEEE Photon. Technol. Lett.*, vol. 22, no. 18, pp. 1835-1838, September 2013.
- [8] M. C. Jeruchim, "Techniques for estimating the bit error rate in the simulation of digital communication systems," *IEEE J. Sel. Areas Commun.*, vol. 2, no. 1, pp. 153-170, January 1984.